

Flying in the Face of Uncertainty: Human Risk in Space Activities

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I. INTRODUCTION

Although the idea remains exceedingly controversial, momentum is building in the US space program for an ever-increasing role of humans in space. This momentum is evident in the renewed emphasis on human exploration of the moon and Mars. It is also evident in the private sector's growing interest in space tourism. Even if the move to greater involvement of humans in space is gradual, space exploration and tourism are attracting the government and private funding necessary to underwrite initial steps in this direction.

The largely overlooked public policy issue of managing human risk in space is an important aspect of these activities. Such risk may be borne by first parties—the actual space travelers themselves. It may also be borne by third parties, such as those positioned on the ground beneath the flight path of a space launch vehicle. Critics of manned flight often argue for robotic exploration, claiming that samples from Mars and other environments could instead be collected by unmanned probes and returned to Earth for study. Human risk, however, is not avoided. Biological contamination associated with the introduction of extraterrestrial materials to the Earth's environment remains an issue.

Managing risk is complex in space activities that can substitute robots for humans and can pose risks to first and to third parties. In addition, space activities and attendant risks involve both the government and the private sector. Sound risk management calls for appropriate application, balancing, and coordination of regulation, legislation, and other forms of policy intervention. The increasingly large private-sector role in space also calls for greater consideration of the advantages and disadvantages of relying on conventional

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practices, such as tort liability and insurance, as alternatives to government intervention in designing public policy.

The purpose of this article is not to define this balance—largely because the precursor analyses of this wide range of issues have yet to take place within the regulatory, legal, and policy communities. Rather, the purpose is to offer a foundation for future analyses by offering background on the types of risks associated with possible loss of life in space projects. It is important to note that zero risk in space activity is unattainable and is an unreasonable policy objective as long as any space projects take place. The objective is not to eliminate risk but to accept it: to manage it through incentives, regulation, and legislation and to rationally decide how much to accept based on commensurate, expected benefit. This article is also not intended to be alarmist about human risk in space activities. Instead, the article seeks to provoke dispassionate public policy discourse about these risks. An implicit theme in the article is that, to the extent the public supports space projects, attitudes must become much more accepting of risk.

The next section describes risk in four activities selected to illustrate risks to humans in space projects. The concluding section draws out general themes and poses questions for designing a framework for policy, regulatory, and legislative management of space risk.

II. SPACE ACTIVITIES AND POSSIBLE HUMAN RISKS

The most prominent space activities that represent the range of risks to first and third parties and the spectrum of risks from private and government space projects are human space exploration, space tourism, planetary protection, and space transportation.

A. HUMAN EXPLORATION OF SPACE

Sending humans into space unquestionably involves risk. Perhaps the most notable manifestations of this risk were the fatal accidents that occurred with *Apollo 1* and with the shuttles *Challenger* and *Columbia*. The policy response to these events is illustrative of as-yet-unresolved problems in risk management.

After each incident, investigations by Congress, Presidential commissions, and NASA led to engineering redesign—a technological fix. In each case, these reviews also recommended changes in how space activities are conducted, largely with respect to how safety concerns are communicated in large organizations like NASA.¹ While accident review and remedial action are fully

¹ See Presidential Commission on the Space Shuttle Challenger Accident, Report to the President 198–201 (1986), available online at <<http://science.ksc.nasa.gov/shuttle/missions/51->

appropriate, the recurrence of these accidents illustrates that spaceflight remains risky even after exhaustive, detailed, and careful investigation, extensive re-engineering, and changes in communication. Another pattern evident in the national experience with these accidents is the long amount of time that elapses between the accident and the return to flight. This trend harbors important implications for the degree to which the risk of flight might be more readily accepted. In particular, the tendency for a long standdown in the space program after an accident is at loggerheads with meeting the timeline set forth in President Bush's 2004 vision of sending humans to the moon by 2020 for moon-based exploration and lunar resource development in preparation for human exploration of Mars.

The *Apollo* and shuttle accidents illustrate these points. In the case of *Apollo 1*, the three-man crew of the *Apollo* command module died in a fire on the launch pad during a preflight test at Cape Canaveral on January 27, 1967.² They were training for the first manned *Apollo* flight. It would be twenty months before the next manned *Apollo* mission (an unmanned mission was flown in November 1967).³ First NASA and then Congress conducted exhaustive investigations of the accident. The reviews concluded that the most likely accident cause was a spark from a short circuit, but that the precise point of origin of the fire could not be positively identified.⁴ The large amount of flammable material in the module and its oxygen-rich environment allowed the fire to start and to spread quickly.

Experts also concluded that other factors materially contributed to the *Apollo 1* accident. These factors were deemed major oversights: the amount of flammable material in the module; the absence of emergency equipment or personnel on the launch pad because the test was a simulation and not considered hazardous; the lack of emergency exits or procedures for the crew; and the communication of safety concerns between NASA and its contractors.⁵ Changes were implemented over the next year-and-a-half, including designing a

1/docs/rogers-commission/table-of-contents.html> (visited Feb 15, 2005). See also generally *Columbia Accident Investigation Board*, 1 *Columbia Accident Investigation Board Report* 226–27 (NASA and GPO 2003), available online at <<http://www.caib.us/news/report/default.html>> (visited Feb 15, 2005); *Apollo 204 Review Board*, Final Reports 5–12 (GPO 1967), available online at <<http://history.nasa.gov/Apollo204/content.html>> (visited Feb 22, 2005); W. David Compton, *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions* (NASA 1989), available online at <<http://www.hq.nasa.gov/office/pao/History/SP-4214/contents.html>> (visited Feb 10, 2005).

² See <<http://history.nasa.gov/Apollo204/>> (visited Feb 22, 2005).

³ See <<http://www.hq.nasa.gov/office/pao/History/apollo/welcome.html#chart>> (visited Feb 22, 2005).

⁴ *Apollo 204 Review Board*, Final Reports at Part IV(3) (cited in note 1).

⁵ *Id.*

new hatch which opened outward and could be operated quickly and removing much of the flammable material and replacing it with self-extinguishing components.⁶

The space shuttle *Challenger* accident on January 22, 1986 was attributable to engineering design, poor management and accountability, and a host of oversights. After the accident, thirty-two months elapsed before the next shuttle mission was launched.⁷ The Presidential commission investigating *Challenger* cited the cause of the disaster as a failure of an “O-ring” seal in one of the shuttle’s solid-fuel rockets.⁸ The faulty design of the seal coupled with unusually cold weather let hot gases leak through the joint, and flames then burned through the external fuel tank and one of the supports that attached the booster to the side of the tank. That booster broke loose and collided with the tank, piercing the tank’s side. Liquid hydrogen and liquid oxygen fuels from the tank and booster mixed and ignited, causing the *Challenger* to tear apart.⁹

The commission not only found fault with the failed sealant ring, but also with the officials at NASA who allowed the shuttle launch to take place despite concerns voiced by engineers.¹⁰ The entire space shuttle program was grounded during the investigation and did not resume flying until shuttle designers made several technical modifications and NASA management implemented stricter regulations regarding quality control and safety.

After the February 1, 2003 accident of the shuttle *Columbia*, the review carried out by the *Columbia* Accident Investigation Board (“CAIB”) found physical failures of the spacecraft design and underlying weaknesses in NASA’s organization as the principal contributors to the incident.¹¹ The Board determined that a breach in the thermal protection system on the wings was the physical cause of the accident. The organizational causes ranged from schedule pressures to characterization and management of the shuttle as operational rather than developmental.¹² The CAIB faulted inadequate testing to fully understand the shuttle’s performance, organizational barriers that stifled differences of opinion and prevented effective communication about safety, and informal, poorly documented decisionmaking within the regular chain-of-

⁶ See Compton, *Where No Man Has Gone Before* (cited in note 1).

⁷ See <<http://www.spaceflight.nasa.gov/shuttle/archives/year1988.html>> (visited Feb 22, 2005).

⁸ Presidential Commission on the Space Shuttle Challenger Accident, Report to the President at 40 (cited in note 1).

⁹ Id at 20–21.

¹⁰ Id at 82, 104.

¹¹ *Columbia* Accident Investigation Board, 1 *Columbia Accident Investigation Board Report* at 49, 177 (cited in note 1).

¹² Id at 177.

command.¹³ As of late March 2005, the shuttle system was expected to resume flying in spring 2005—about eighteen months after the accident.

In addition to its detailed review of the *Columbia* event, the CAIB offered a broader conclusion: the conviction that “operation of the Space Shuttle, and all human spaceflight, is a developmental activity with high inherent risks.”¹⁴ Future spacecraft developed to ferry humans to the moon and Mars will be radically new types of vehicles that must meet even more challenging flight conditions than did *Apollo* or the shuttles. The new spacecraft will need to be able to withstand the extreme heat, cold, radiation, and duration requirements that will be encountered on future missions. Each successive mission is expected to involve stages of evolution of “crew exploration vehicles,” with each stage incorporating more demanding physical capabilities.¹⁵ The program timing will likely make each vehicle and each flight a unique experiment with new, unknown risks (it is not clear how many of the new vehicles will be used more than once if they are to evolve to ever-increasing capability). The shuttle program at the time of the *Columbia* accident had accumulated 32 years of experience and 113 flights (including *Columbia*’s 28th).¹⁶ Yet according to the CAIB, the shuttles were still developmental.¹⁷

Under the experimental conditions of new flight vehicles for human missions to the moon and Mars, risks to astronauts are likely to increase. Anecdotes indicate that astronauts generally are prepared to accept these risks. David Compton wrote about reasons for this acceptance during the *Apollo* project.¹⁸ He described the extensive involvement of astronauts in the construction and testing of their launch vehicles and command modules, and concluded that astronauts were fully aware of the technical risks and operational uncertainties.¹⁹ That Compton’s assessment also pertains to today’s astronaut corps is suggested by trends in applications submitted by individuals to become astronauts. Specifically, NASA data on the number of fully qualified candidates for the astronaut corps show that the number of qualified candidates either

¹³ Id.

¹⁴ Id at 9.

¹⁵ See generally National Aeronautics and Space Administration (“NASA”), Vision for Space Exploration, available online at <http://www.nasa.gov/missions/solarsystem/explore_main.html> (visited Mar 28, 2005).

¹⁶ *Columbia Accident Investigation Board*, 1 *Columbia Accident Investigation Board Report* at 27 (cited in note 1).

¹⁷ Id at 9.

¹⁸ See Compton, *Where No Man Has Gone Before* (cited in note 1).

¹⁹ Id at 92.

remains constant or increases following shuttle accidents.²⁰ Much like the cadre of pioneers of aviation during the early twentieth century, the modern astronaut corps does not appear to have been disheartened by accidents. Moreover, the size of the corps exceeds the number of candidates ever expected to have the opportunity to fly.²¹

If the supply of flight-qualified astronauts is resilient to a level of risk that characterizes manned spaceflight, then policymakers have at least one benchmark for ascertaining an appropriate degree of risk for human exploration projects. This benchmark is, essentially, determined by this supply. So long as the supply of qualified candidates is equal to or exceeds the number of astronauts required for the program, the program is balancing risk at levels that these individuals are willing to undertake. The cost of attaining and maintaining such a benchmark can also play another role: it can be informative in balancing investment in human space exploration with its alternative—robotic exploration.

The advances in computing and robotic technology since the *Apollo* and shuttle programs (over the past forty years in the case of *Apollo*, and the past twenty years in the case of the shuttle) make unmanned exploration a very close substitute for human exploration. High-resolution, high-speed, and high-quality animation and the graphics of computerized virtual reality can readily be combined with data sent back by unmanned probes. For those who want to see and even touch Mars, interplanetary robots can do this as well—by gathering samples and then returning them to Earth. Years ago, spacecraft brought back moon rocks. In 2004, a low-cost NASA spacecraft, *Stardust*, collected samples of comet and interplanetary dust (the samples will be returned to Earth via parachute in 2006.)²² Advances in unmanned data collection from space and other innovations in information technology are improving so rapidly that robotic success could even undo human exploration and enable sophisticated “stay-at-home” explorers. Robots in the near future are likely to be able to make split-second decisions and display the spirit of inquiry that human explorers bring (just as the NASA probe *Spirit* began its journey on Mars, British scientists reported the first robot capable of theorizing, reasoning, and actively learning).²³

²⁰ NASA, Report of the Assistant Inspector General for Auditing, *Improving Management of the Astronaut Corps* at Appendix C, Table 5 (June 27, 2003), available online at <http://www.hq.nasa.gov/office/oig/hq/inspections/g-01-035.pdf> (visited Mar 27, 2005).

²¹ Id at 3–4.

²² See NASA, Jet Propulsion Laboratory, *Stardust: NASA's Comet Sample Return Mission*, available online at <http://stardust.jpl.nasa.gov/> (visited Mar 27, 2005).

²³ John Roach, “Robot Scientist” Said to Equal Humans at Some Tasks, National Geographic News (Jan 14, 2004), available online at http://news.nationalgeographic.com/news/2004/01/0114_040114_robot.html (visited Mar 4, 2005).

Balancing manned and robotic exploration—based in part on a comparison of human risk—is only part of a decision about future space activities. But the current generation of decisionmakers, including many in Congress and at NASA, has not been daring about flying in the face of such perils. Some observers assert that reasons for lengthy Congressional investigations of space accidents extend beyond accident investigation and are, instead, the agenda of political actors intent on decreasing the funding of space exploration.²⁴ Whatever the reasons for delay before flight is resumed, these hold-ups run counter to proposed timescales for sending humans to the moon or to Mars. While spaceflight accidents may never be taken in the stride of auto or aviation accidents, the pursuit of human spaceflight requires greater acceptance of the outcome that lives will be lost. The early days of aviation and the contemporary model of testing experimental military aircraft offer paradigms that may be useful in framing how to strike the balance among risk responses for policymakers.

B. SPACE TOURISM

A privately built and financed spacecraft, *SpaceShipOne*, succeeded in 2004 in launching and returning humans to sub-orbital space (an altitude of sixty-two miles) twice within six days.²⁵ The team behind the spacecraft collected the ten million dollar Ansari X Prize and magnified attention to *private* human spaceflight.²⁶ (For several years, Russia has offered seats on its *Soyuz* spacecraft for about twenty million dollars per passenger and has twice flown tourists.)²⁷ After the success of *SpaceShipOne*, a British businessman, Richard Branson, quickly entered into a licensing agreement with the owners to build five spacecrafts for passengers. Branson's business plan within the next three years is to fly fifty passengers a month—each paying two-hundred thousand dollars for a two-hour flight.²⁸ Shortly after the agreement, a hotel magnate offered another

²⁴ See Compton, *Where No Man Has Gone Before* (cited in note 1).

²⁵ See <http://www.scaled.com/projects/tierone/041004_spaceshipone_x-prize_flight_2.html> (visited Mar 27, 2005).

²⁶ Id.

²⁷ See Spacetoday.net, *Russia to Reopen Soyuz Flights to Tourists*, available online at <<http://www.spacetoday.net/Summary/1727>> (visited Feb 22, 2005); Thinkquest.org, *Space Travel 101: Fundamentals of Space Travel*, available online at <<http://library.thinkquest.org/03oct/01581/SpaceTravelEnglish/manned/text/soyuz.html>> (visited Mar 27, 2005).

²⁸ Spencer Reiss, *Rocket Man*, *Wired Mag* 140 (Jan 2005), available online at <www.wired.com/archive/13.01/branson_pr.html> (visited Feb 15, 2005).

prize, for fifty million dollars, for the first private-manned mission to orbit the Earth.²⁹

Currently, any individual or private entity wishing to conduct a commercial launch or reentry (when a launch vehicle returns to Earth), or operate a launch or reentry site in the US must obtain a license from the Federal Aviation Administration (“FAA”). To date, the vehicles have been unmanned, with the exception of *SpaceShipOne*. In the wake of *SpaceShipOne*’s success, the US Congress has debated how to regulate commercial human spaceflight, arguing at length about how to handle crew and passenger safety and the appropriate scope of authority to be vested with the government.³⁰ Some legislators supported allowing privately-owned and operated spacecraft to carry paying passengers on a “fly at your own risk” basis.³¹ This proposal would make private spaceflight relatively free from regulation, much like the early aviation barnstorming era. The Associate Administrator for Commercial Space Flight at the FAA expressed a view that passengers “should be able to board their vehicles with the same freedom as the stunt pilots who pioneered commercial aviation.”³²

Draft bills proposed regulating, training, and setting standards for the medical condition of crews, informing passengers of the risks of their participation, and requiring passenger consent to safety-related risks associated with the spaceflight.³³ Another topic was the use of mutual waivers of liability with licensees and the federal government.³⁴ The extent of the government’s role was also controversial in congressional hearings. The industry wanted loose oversight, claiming that federal authority should be limited to safeguarding the uninvolved public (such as populations living under the flight path of the spacecraft).³⁵

Much of the debate centered on whether space tourism is analogous to commercial aviation or a more unique activity for which the approach to

²⁹ *Manned Spaceflight: SpaceShipWon*, Economist 75 (Oct 9, 2004).

³⁰ See, for example, Hearings on Commercial Space Transportation before the House Committee on Transportation and Infrastructure, 108th Cong, 2d Sess 1 (Feb 2005), available online at <<http://www.spaceref.com/news/viewsr.html?pid=15408>> (visited Mar 27, 2005).

³¹ See *id.*

³² Peter B. deSelding, *FAA Urges Liability Leeway for Space Pioneers*, SpaceNews.com (Dec 2, 2004), available online at <http://dev.space.com/spaceneWS/spacepolicy/ISU_120204.html> (visited Mar 4, 2005).

³³ See Commercial Space Launch Amendments Act of 2004, HR Rep No 108-429, 108th Cong, 2d Sess 3 (2004), available online at <<http://thomas.loc.gov/cgi-bin/cpquery/T?&report=hr429&dbname=cp108&>> (visited Mar 3, 2005).

³⁴ *Id.*

³⁵ *Id.* at 5.

regulating commercial aviation is inappropriate. Discussion in the CAIB report offers some comparisons:

Although humans have been launching orbital vehicles for almost 50 years now—about half the amount of time we have been flying airplanes—contrast the numbers. Since *Sputnik*, humans have launched just over 4,500 rockets towards orbit (not counting suborbital flights and small sounding rockets). During the first 50 years of aviation, there were over one million aircraft built. Almost all of the rockets were used only once; most of the airplanes were used more often. ... In the early days as often as not the vehicle exploded on or near the launch pad; that seldom happens any longer. It was not that different from early airplanes, which tended to crash about as often as they flew. Aircraft seldom crash these days, but rockets still fail between two and five percent of the time. This is true of just about any launch vehicle [including the shuttle] It is unlikely that launching a space vehicle will ever be as routine an undertaking as commercial air travel—certainly not in the lifetime of anybody who reads this.³⁶

The CAIB further comments:

Because of the dangers of ascent and re-entry, because of the hostility of the space environment, and because we are still relative newcomers to this realm, operation of the shuttle and indeed all human spaceflight must be viewed as a developmental activity. It is still far from a routine, operational undertaking. Throughout the *Columbia* accident investigation, the Board has commented on the widespread but erroneous perception of the space shuttle as somehow comparable to civil or military air transport. They are not comparable; the inherent risks of spaceflight are vastly higher, and our experience level with spaceflight is vastly lower.³⁷

The CAIB perspective succinctly leads to the mantra for space tourism of “fly at some risk.” While the final version of the legislation for regulating space tourism has a preamble statement recognizing that space transportation is inherently risky, the specific provisions only loosely regulate passenger safety.³⁸ The legislation that emerged, in the Commercial Space Launch Amendments Act of 2004,³⁹ allows private spacecraft to be licensed on an “experimental” basis and establishes liability guidelines.⁴⁰ The statute provides a legal basis for allowing private and commercial passengers to undertake space travel and establishes the concept of informed risk for space passengers.⁴¹ The government

³⁶ *Columbia* Accident Investigation Board, 1 *Columbia Accident Investigation Board Report* at 19 (cited in note 1).

³⁷ *Id.* at 208.

³⁸ See Commercial Space Launch Amendments Act of 2004, Pub L No 108-492, 118 Stat 3974 (2004), codified at 49 USC §§ 70101–21 (2004).

³⁹ See *id.*

⁴⁰ 49 USC § 70105(a).

⁴¹ See Commercial Space Launch Amendments Act of 2004 § 2(13)(5)(c), 118 Stat at 3974.

can also, for the next eight years, restrict or prohibit design features or operating practices that have resulted in or could have contributed to a serious or fatal injury to crew or passengers during a licensed flight.⁴² The eight-year sunset provision is intended to allow safety standards to evolve in the industry and to permit revision of the standards.

An argument against further or more stringent regulation could be based on the assumption that any passenger deaths are likely to discourage flight to a much sharper degree than in aviation. In an interview about privately offered human spaceflight, its backers note that “one [fatal] incident can put the whole business in deep trouble.”⁴³ If this is the case, the industry has strong incentives to self-regulate. Another issue that may arise is whether limits to the liability of space transportation companies for damage claims by passengers are warranted. Such limits could be the spaceflight counterparts to the Warsaw Convention (“Convention”).⁴⁴ Among other provisions, the Convention limits the financial liability of air transportation companies to damages claimed by passengers for themselves, cargo, and baggage, and also establishes uniformity with respect to liability among the countries that are signatories.⁴⁵ The Convention was established in the early days of commercial aviation, in part to protect the nascent industry financially.

C. SPACE TRANSPORTATION

Before 1984, the US government was the sole provider of space launch services in the US. The government contracted for unmanned space launch vehicles from the private sector (companies such as Lockheed Martin and Boeing) or provided its own vehicles, such as the space shuttle. Since that time, more than 150 launches by US space transportation companies have taken place for commercial satellites providing telephony, television, paging, and other services.⁴⁶ Although most commercial launches are from federal launch ranges,

⁴² Id at § 2(14)(d)(3).

⁴³ Reiss, *Rocket Man*, *Wired Mag* at 180 (cited in note 28).

⁴⁴ Convention for the Unification of Certain Rules Relating to International Carriage by Air, 49 Stat 3000 (1929), available online at <<http://www.jus.uio.no/lm/air.carriage.warsaw.convention.1929/doc.html>> (visited Mar 27, 2005).

⁴⁵ Id, arts 17–30.

⁴⁶ US Department of Transportation (“USDOT”) and Federal Aviation Administration (“FAA”), *Liability Risk-Sharing Regime for U.S. Commercial Space Transportation: Study and Analysis*, chapt 3 at 26 (Apr 2002), available online at <<http://ast.faa.gov/files/pdf/FAALiabilityRiskSharing4-02.pdf>> (visited Mar 27, 2005).

the private space transportation industry also operates non-federal launch sites, or spaceports, in California, Florida, Virginia, and Alaska.⁴⁷

All commercial launches from federal ranges take place under federal launch range safety requirements administered by the US Air Force and the FAA.⁴⁸ The FAA also licenses operation of the spaceports. The principal safety issues pertain to workers at the launch site and to the public within the flight path of the launch (including people and property on land as well as, say, fishing fleets, ocean tankers, and cruise ships at sea and under the flight trajectory).

Two multilateral treaties specifically address liability associated with space transportation. The 1967 Outer Space Treaty assigns liability to the nation from which a space vehicle is launched for damage to other signatories. The vehicle may be a government or commercial launch vehicle.⁴⁹ The 1972 Convention on International Liability for Damage Caused by Space Objects (“Liability Convention”) provides for compensation for parties injured by space-related activities.⁵⁰ The Liability Convention defines whether liability is absolute or fault-based depending on where the damage occurs. If damage is on the ground or to aircraft in airspace, absolute liability applies. If damage occurs to spacecraft in orbit or elsewhere, a fault-based standard applies.⁵¹

Under the Commercial Space Launch Act of 1984, the US Department of Transportation has launch licensing jurisdiction to implement obligations of the US under these treaties.⁵² In amendments to this Act in 1988, part of the launch license issued to a commercial space transportation company requires insurance in an amount to cover the most probable loss to third parties for damage, injury, or loss.⁵³ The amount of required liability insurance is determined by government estimates of the maximum probable loss (“MPL”). The MPL is based on the past performance of the launch vehicle and its flight trajectory

⁴⁷ FAA, AST, 2004 *U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports* 45, Table C (Jan 2004), available online at <http://ast.faa.gov/info_vsite/launch_vehicles.htm> (visited Mar 27, 2005).

⁴⁸ USDOT and FAA, *Liability Risk-Sharing Regime for U.S. Commercial Space Transportation*, chapt 3 at 8 (cited in note 46).

⁴⁹ Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967), art 7, 18 UST 2410 (1969) (“Outer Space Treaty”).

⁵⁰ Convention on International Liability for Damage Caused by Space Objects (1972), 24 UST 2389 (1974).

⁵¹ *Id.*, arts 2–3.

⁵² Commercial Space Launch Act of 1984, Pub L No 98-575, 98 Stat 3055 (1984), codified at 49 USC § 70101–301 (2000).

⁵³ Commercial Space Launch Act Amendments of 1988, Pub L No 100-657, 102 Stat 3900 (1988), codified at 49 USC § 70112 (2004).

(which takes into account the population of areas under the flight path). The MPL calculation requires that the public should face no more than a one-in-a-million chance of fatality from launch vehicle operations, including commercial space launch and reentry operations.⁵⁴

The amount of liability insurance per flight can go up to a statutory ceiling of five hundred million dollars, or the maximum available on the world market for space insurance—whichever is less. Up to 1.5 billion dollars beyond that amount (adjusted for inflation between 1988 and the current year) may be appropriated by Congress to cover catastrophic claims. Financial responsibility above the combined amount of insurance and appropriated funds is borne by the launch operator unless it can show no liability.⁵⁵

The original intent of the 1988 provisions was to financially underwrite what was deemed to be a nascent commercial space transportation industry and to enable US companies to be price-competitive with foreign launch vehicles in attracting customers from around the world (foreign vehicles—largely from Russia, Ukraine, China, and France—have little or no indemnification).⁵⁶ The provisions for indemnification were initially to expire in 1993; Congress has extended the provisions twice, and at present they expire in 2006.⁵⁷ In 2004, Congress required the FAA to contract an outside study to determine whether the provisions are still likely to be necessary beyond 2006.⁵⁸

In a 2002 study commissioned by the FAA, indemnification was not found to be a significant factor in the price-competitiveness of US launch vehicles.⁵⁹ Part of the reason is the flawless safety record of the vehicles. No injuries or fatalities to third parties have occurred in the decades-old history of the US industry.⁶⁰ In addition, the study found that the commercial space insurance market appeared to have adequate capacity to provide full insurance coverage based on estimates of MPL.⁶¹ Another argument for terminating indemnification was the side effect of any potential bias it may bring to the industry's incentives to engage in safety innovation. Companies may reallocate internal budgets away from safety research and development that would otherwise be undertaken in the absence of the safety net of government backing. The 2002 study suggested some possible market-like alternatives to government indemnification, including

⁵⁴ USDOT and FAA, *Liability Risk-Sharing Regime*, chapt 1 at 10, chapt 7 at 16 (cited in note 48).

⁵⁵ *Id.*, chapt 1 at 10–11, chapt 7 at 18.

⁵⁶ *Id.*, chapt 4 at 1–2, 4–5, 7, 9.

⁵⁷ Commercial Space Launch Amendments Act of 2004, 118 Stat at 3974.

⁵⁸ *Id.*

⁵⁹ USDOT and FAA, *Liability Risk-Sharing Regime*, chapt 3 at 29 (cited in note 48).

⁶⁰ *Id.*, chapt 3 at 9.

⁶¹ *Id.* at D-4.

the implementation of insurance pools for self-insurance, the issuance of bonds, and the establishment of trust funds.⁶²

Although, as noted, US spaceflight has a flawless public safety record, the CAIB report provides some additional perspective in comments on the third-party risk associated with shuttle flights.⁶³ The shuttle Columbia's flight path upon reentry was over California, Nevada, New Mexico, Texas, and Louisiana. Debris spread over two thousand square miles and over seven-hundred thousand acres were searched. No one was injured and little property damage resulted from the debris, leading the NASA Administrator to proclaim that this outcome "was a 'miracle.'"⁶⁴ The *Columbia* disintegrated over a relatively sparsely populated area of the US, with an average of about eighty-five inhabitants per square mile. Other shuttle reentry flight paths often pass over much more populated areas, including major cities with more than one thousand inhabitants per square mile.⁶⁵

D. PLANETARY PROTECTION⁶⁶

Planetary protection refers to two situations. One situation is protecting Earth from microorganisms that may be brought back in samples of soil, rocks, and other materials collected from extra-terrestrial bodies during scientific space exploration. The other situation is protecting the solar system—planets, moons, asteroids, and comets—from Earth life introduced when spacecraft land on or impact with these bodies. The case of contaminating other bodies is known as "forward contamination" and the case of contaminating Earth is known as "backward contamination." A related situation of possible contamination surrounds the samples themselves. The samples must be collected and handled in a manner to protect them from contamination by terrestrial organisms in order to preserve the integrity of the samples.⁶⁷

⁶² Id, ch 9 at 4, 9.

⁶³ See *Columbia Accident Investigation Board*, 1 *Columbia Accident Investigation Board Report* at chapt 10 (cited in note 1).

⁶⁴ Id at 213 (quoting Sean O'Keefe, NASA Administrator).

⁶⁵ Id.

⁶⁶ Much of the discussion in this section is from John Rummel and Linda Billings, *Issues in Planetary Protection: Policy, Protocol and Implementation*, 20 *Space Poly* 49–54 (2004).

⁶⁷ More recently, concern about forward contamination has included another rationale for protection. This reason is the idea that it is unethical to contaminate the Martian surface. There is some discussion among scientists as to whether missions to Mars have already contaminated the planet. Three Soviet spacecraft and four NASA spacecraft have landed or crashed on Mars. The desirability of environmental remediation of potential contamination on Mars is also among concerns.

Planetary protection has long been a concern in space exploration. For instance, to prevent backward contamination, the lunar samples collected by the *Apollo* astronauts, as well as the astronauts themselves, were quarantined upon return to Earth.⁶⁸ As an example of preventing forward contamination, before launching the US *Viking* missions to Mars in the 1970s, NASA cleaned the Mars landers to reduce bacterial spores, packaged the landers in a protective shield, and baked the packaged spacecraft to sterilize them to avoid contaminating Mars.⁶⁹ The rationale at that time was to avoid contamination in introducing life from Earth into the Martian environment and thereby confounding analysis of the soils on the surface of Mars in looking for evidence of life.⁷⁰ To take another example, the National Academy of Sciences recommends that missions to Jupiter's moon Europa be designed, cleaned, and operated to not exceed a one in ten thousand chance of introducing any viable Earth life to Europa.⁷¹

Signatories to the 1967 United Nations Outer Space Treaty agree to regulate both types of interplanetary contamination.⁷² The treaty states that the exploration of planetary bodies will be conducted “so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.”⁷³ An international committee, the Committee on Space Research (“COSPAR”), coordinates international activities related to interplanetary protection.⁷⁴ NASA also maintains a planetary protection office.⁷⁵ The Planetary Protection Officer at NASA is responsible for overseeing every space mission to ensure that it implements relevant protection measures.

The human risks associated with planetary contamination are wide ranging. They include risks to the general public when samples are returned to Earth from space, risks to astronauts who collect samples during space missions, risks to scientists and others who handle samples for analysis, and risks to life that

⁶⁸ Space Studies Board, *The Quarantine and Certification of Martian Samples*, Appendix B (Nat'l Academies 2002), available online at <<http://books.nap.edu/books/0309075718/html>> (visited Mar 27, 2005).

⁶⁹ Rummel and Billings, 20 *Space Poly* at 51 (cited in note 66).

⁷⁰ “Life” when used in the context of life other than on Earth is generally assumed to mean “life as we know it”—that is, carbon-based. However, there is the possibility of life in forms different from our understanding of life. See Space Studies Board, *The Quarantine and Certification of Martian Samples* at 3, n 3 (cited in note 68).

⁷¹ Rummel and Billings, 20 *Space Poly* at 50 (cited in note 66).

⁷² Outer Space Treaty, art 9 (cited in note 49).

⁷³ *Id.*, art 9.

⁷⁴ Rummel and Billings, 20 *Space Poly* at 50 (cited in note 66).

⁷⁵ See <<http://planetaryprotection.nasa.gov/pp/index.htm>> (visited Mar 27, 2005).

may exist on other planets. In the case of reducing risks to the general public and to scientists analyzing samples, NASA is now considering protocols for sample return and the appropriate design of laboratories to which samples from future Mars missions in the next decade would be taken.⁷⁶ The Space Studies Board of the National Academy of Sciences has recommended that the level of protection from the laboratories should match the strictest security requirement established by the US government for facilities dealing with biological agents and infectious diseases.⁷⁷

Concerns involving planetary protection extend beyond robotic missions. Concerns will also condition the tradeoff between astronaut safety and protecting Earth in future human exploration missions. The first sample returns from other bodies are likely to be collected and returned without humans in space. But in the case of astronauts who may be involved in future missions, a host of issues arise. In the case of the lunar samples returned by *Apollo* astronauts, the quarantine protocol stated: "The preservation of human life should take precedence over the maintenance of quarantine."⁷⁸ If a command module had begun to sink during recovery operations when the module splashed down upon return to Earth, a major fire had broken out in the crew quarters of the receiving lab, or a quarantined astronaut suffered a medical emergency that could not be handled in the quarantine facility, the plan was to 'break quarantine.'⁷⁹ In future missions, astronauts may be asked to sign waivers indicating they understand and accept these kinds of risks.

In all cases, whether involving astronauts or not, planetary protection can be met in part by the design of the mission and the spacecraft. If a spacecraft is designed to orbit a planet rather than land on it, cleanliness requirements are less demanding than if the craft were to land. At the end of a mission, a spacecraft could be orbited long enough for radiation in space to eliminate organisms on the craft's exterior. If a spacecraft is designed to land on a planetary body, only the part that touches the body's surface may need sterilization. In the case of the end of NASA's *Galileo* mission to Jupiter, engineers redesigned the mission to ensure that the spacecraft would burn up in the atmosphere of Jupiter to prevent

⁷⁶ Rummel and Billings, 20 *Space Poly* at 50 (cited in note 66); NASA, *A Draft Test Protocol for Detecting Possible Biobazards in Martian Samples Returned to Earth*, NASA/CP—2002–211842 (Oct 2002), available online at <http://spacescience.nasa.gov/admin/pubs/marssamples/draft_protocol.pdf> (visited Mar 27, 2005).

⁷⁷ See Space Studies Board, *The Quarantine and Certification of Martian Samples* at 1 (cited in note 68).

⁷⁸ Id. at 76.

⁷⁹ Id.

the spacecraft from crashing into one of Jupiter's moons (where some evidence has suggested that there may be water beneath the moons' surfaces).⁸⁰

Upon return to Earth, the level of safety accorded by the design and operation of the laboratory, as well as the transport of the sample materials from the landing site to the laboratory, requires a balance between protection and sample preservation. For instance, it is desirable to store samples from Mars at low (subfreezing) temperatures and in an atmosphere of gas composition and pressure that reproduces the Martian environment. But designing a facility with these characteristics, as well as the operational procedures to handle and study the samples, would be extremely complex.

These protection measures incur costs: both the direct cost of implementation and the indirect cost of affecting the design of the mission to accommodate protection requirements. In the case of some of the more stringent protection requirements, the cost of meeting them on an unmanned Mars sample return mission is estimated to be about 5 to 10 percent of the total budget for the project.⁸¹ For this reason, understanding the risks and allocating risk appropriately among those placed at risk (the public, astronauts, and scientists) is highly important.⁸²

III. CONCLUSIONS

These illustrations of space activities show a range of risks to humans. First-party risks to astronauts and launch vehicle pilots arise in human exploration, space tourism, and space transportation and may arise when humans are involved in spaceflight for sample return. Third-party risks involve terrestrial populations in flight paths and the possibility of contamination from sample returns. International treaties and agreements, government safety regulation of space tourism and space transportation, and government indemnification of commercial space transportation currently exist for addressing some of these risks. However, some general themes among these space activities highlight as yet unresolved risk-related issues. These issues include:

- Lengthy standdowns in spaceflight after loss of life without commensurate reduction in risk;

⁸⁰ Rummel and Billings, 20 *Space Poly* at 53 (cited in note 66).

⁸¹ *Id.* at 52.

⁸² Interestingly, little discussion has addressed the possible use of the international space station or other space-based facilities as isolated places to return and study samples and reduce possible backward contamination.

- The challenge of balancing safety with commensurate benefit of risk taking by first and third parties; and
- An appropriate mix of government and private intervention, including possible use of private insurance markets and tort liability, as breaks with tradition of nonmarket, government prescriptions.

Perhaps the underlying theme of greatest opportunity in this review is the policymakers' attitudes toward space-related risk and their willingness to accept and publicly communicate the inevitability of risk. How best to frame and inform public discussion of space risk and, at the same time, offer appropriate regulatory, legislative, and other policy assurances to balance risk, are immediate questions for analysis.